Climate Change Adaptation Using Seaweed Bed of BioSlag in Marine Environment

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Contents

1. Needs of Adaptation & Mitigation in Coastal Environment
2. Outline of Our Approach
3. Theoretical Backgrounds
   - CCS Method by IPCC
   - Carbonation of Slag
   - Restoration of Seaweed Bed
4. Results of BioSlag Application Study
5. Ongoing Activities with Korean Gov.
6. Conclusions

Needs of Adaptation & Mitigation in Coastal Environment

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007)

➢ Over 20% of Fisheries Grounds in East Coast of Korea Affected by Whitening Phenomena

- **Rise of sea surface temp. (SST)**
- **Bloom of coralline algae**
- **Over-propagation of sea urchin**
- **Poor nutrients in seawater**

※ Examples of Whitening Phenomena in Korea ('04)

Coastal Province	Fisheries Ground (ha)	Whitening Area (ha)	Share (%)
Gangwon	11,216	776	7
Gyeongbuk	6,663	2,110	32
Jeju	14,451	4,541	31
Total	32,330	7,427	23

* Whitening Area in Jeju Island

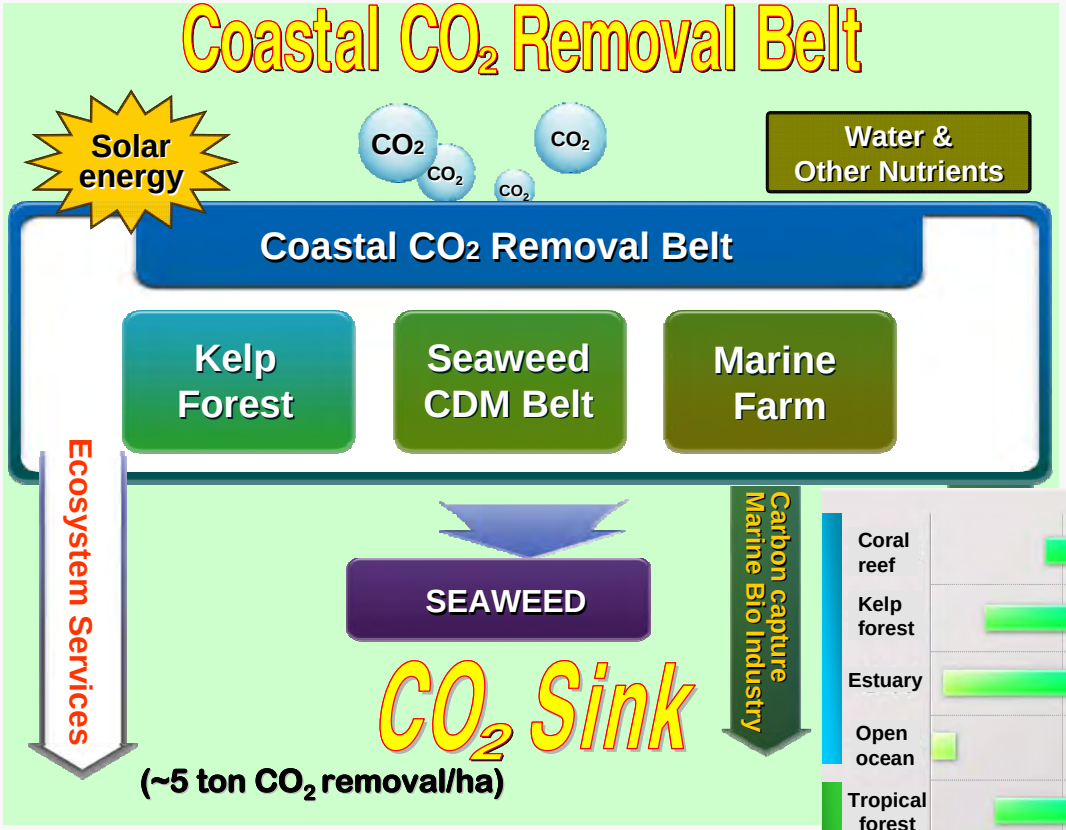
(Red line: '98, Blue line: '04)

('07, Nat'l Fisheries R&D Institute)

✓ **Climate change → SST Rise → Coralline algae bloom → "Whitening" spreading**

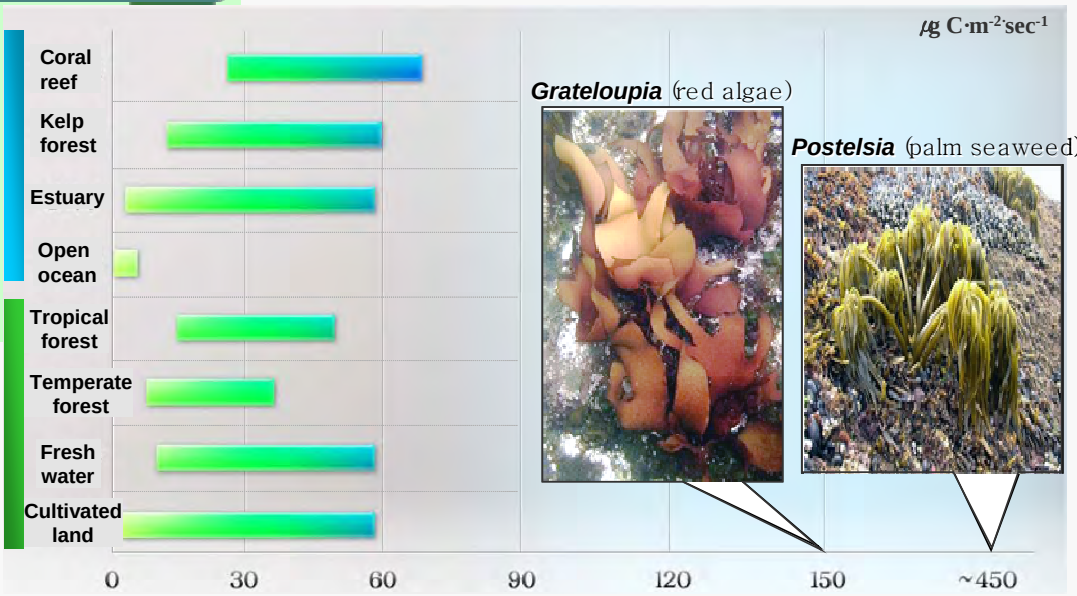
➔ **Coastal desertification**

➢ "Greenhouse Gas Removal by Seaweed" Program in Korea (2006~2012)



- *PI: Prof. Ik Kyo Chung, Pusan Nat'l Univ.*
- *Funded by MLTM (Ministry of Land, Transport and Maritime Affairs)*

CO_2 uptake rate of seaweed



Nat'l Roadmap for Climate Change Adaptation and Mitigation (MLTM, '08.2)

- Supervised by RIST
- MLTM; Ministry of Land, Transport and Maritime

Protection of people's livelihoods & property
Contribution to the retardation of global warming in maritime and fisheries sector of Korea

5 Key Strategies

Adaptation in Coastal Env.
Territorial security

- ✓ Assessment of Risk & Vulnerability
- ✓ Prediction & Retar-dation of Coastal Change due to CC
- ✓ Management of Coastal Env. & Eco-system

Adaptation in Fishery Resources
Food control

- ✓ Monitor. & Predict. Fishery Resources' Variation
- ✓ Manage. & Protect. Fishery Resources
- ✓ Development of New Culture & Catch

Mitigation of GHG in Mar. Env.
GHG reduction

- ✓ Renewable Marine Energy Development
- ✓ Mar. Sink & Storage Tech. Development
- ✓ Management of Discharge Inventory & Energy Efficiency

Building-up Marine Science & Monitoring
CC Research

- ✓ Nat'l Std. Predictive Model for Mar. CC
- ✓ Science of Currents & Sea-level Change
- ✓ Monitoring & Prediction of Eco-system Impacts

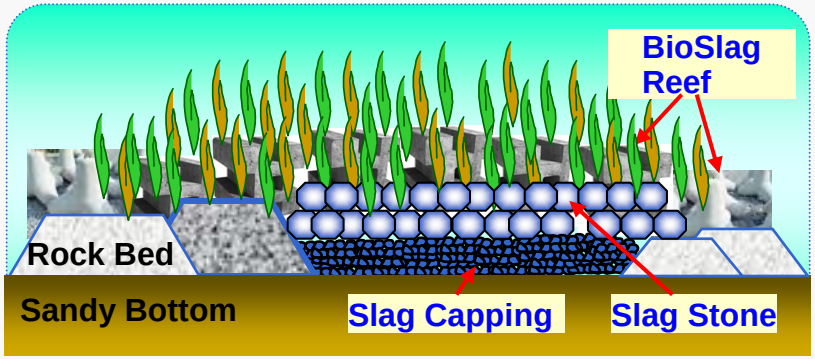
Strengthening Policy Making
Policy decision

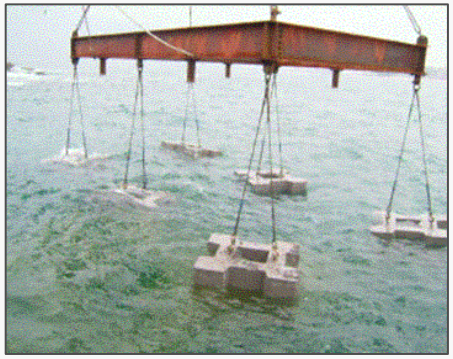
- ✓ Preparation of 2012 YEOSU EXPO
- ✓ Education & Train Marine CC Expert
- ✓ Int'l Cooperative Network for CC

Outline of Our Approach; Adaptation & Mitigation

➢ Restoration of Seaweed Beds using BioSlag in Vulnerable Coastal Area

(Adaptation)

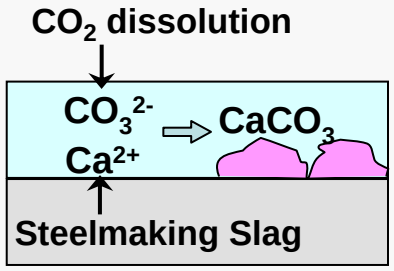




- Material stabilized by cooling after melting it over 1,500℃ during steelmaking process
- Higher contents of Fe, Ca

➢ CO_2 Mitigation by Slag Carbonation & Seaweed Photosynthesis

(Mitigation)

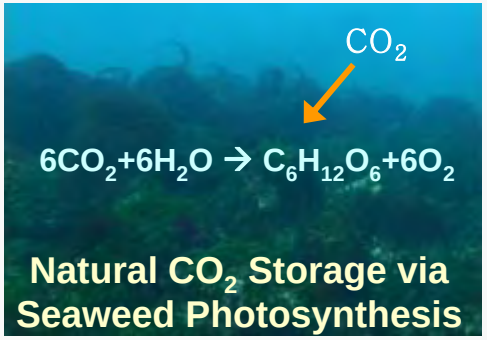


In-House CO_2 Sequestration via Steel Slag Carbonation

(0.3 t-CO_2 ↓ /ton-slag)

Seaweed Reef of BioSlag

(0.79 t-CO_2 ↓ /ton-slag cement)

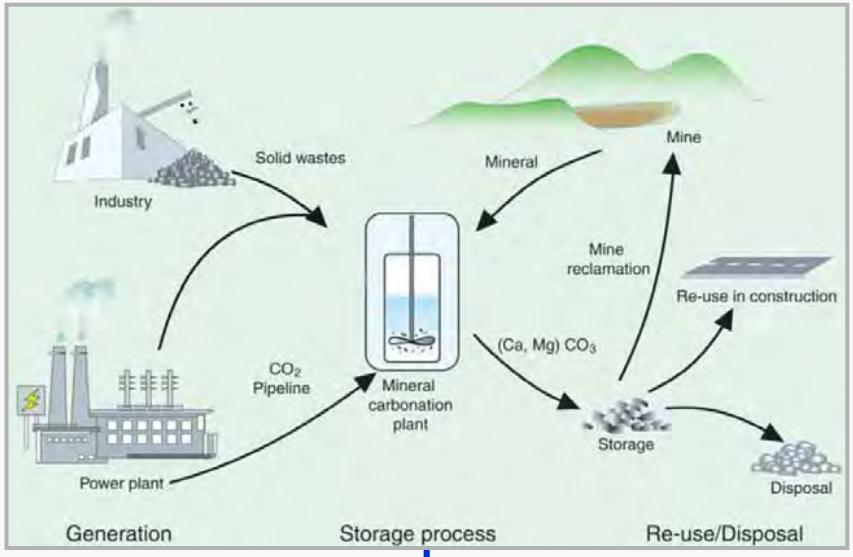


(0.1~0.5 t-CO_2 ↓ /ton-slag·yr)

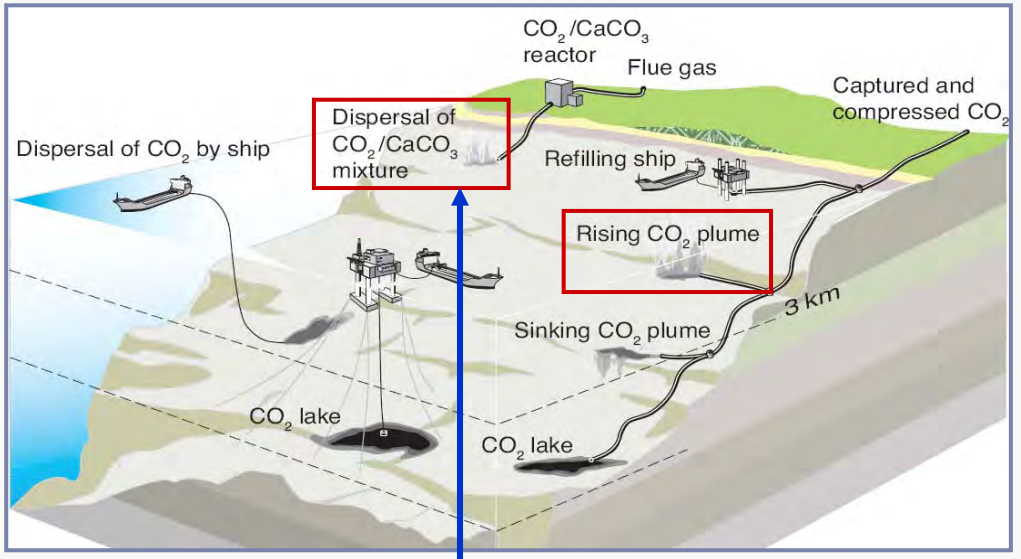
Theoretical Backgrounds

Carbon Capture & Storage (IPCC Technical Summary, 2005)

Mineral Carbonation Method



Ocean Storage Method



Slag Carbonation

Installation of Slag Seaweed Reef

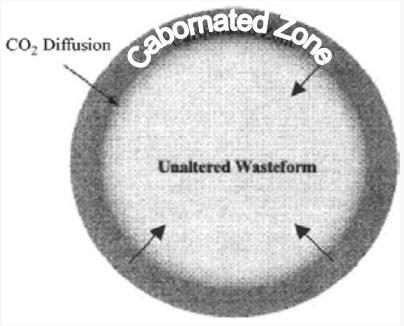
In-house CO_2 Sequestration

Natural CO_2 Storage by Seaweeds

CO_2 Mitigation & Adaptation to Coastal Climate Change

Carbonation Mechanism

Schematic of carbonation process



Aqueous carbonation of calcium oxide

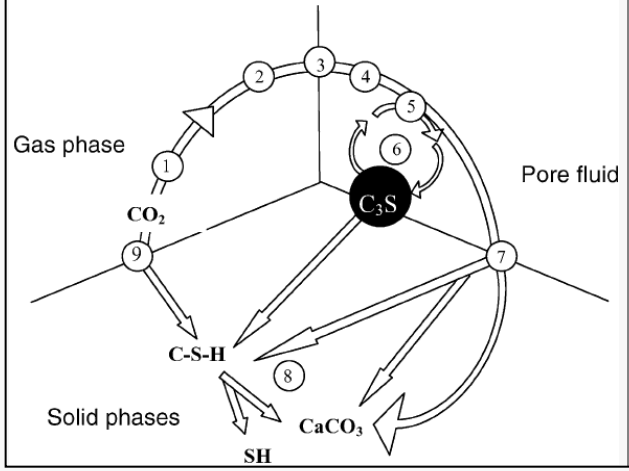
$$CO_2(g) + H_2O(l) \rightarrow 2H^+(aq) + CO_3^{2-}(aq)$$

$$CaO(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l)$$

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3\downarrow(s)$$

(Environ. Sci. Technol. 2005)

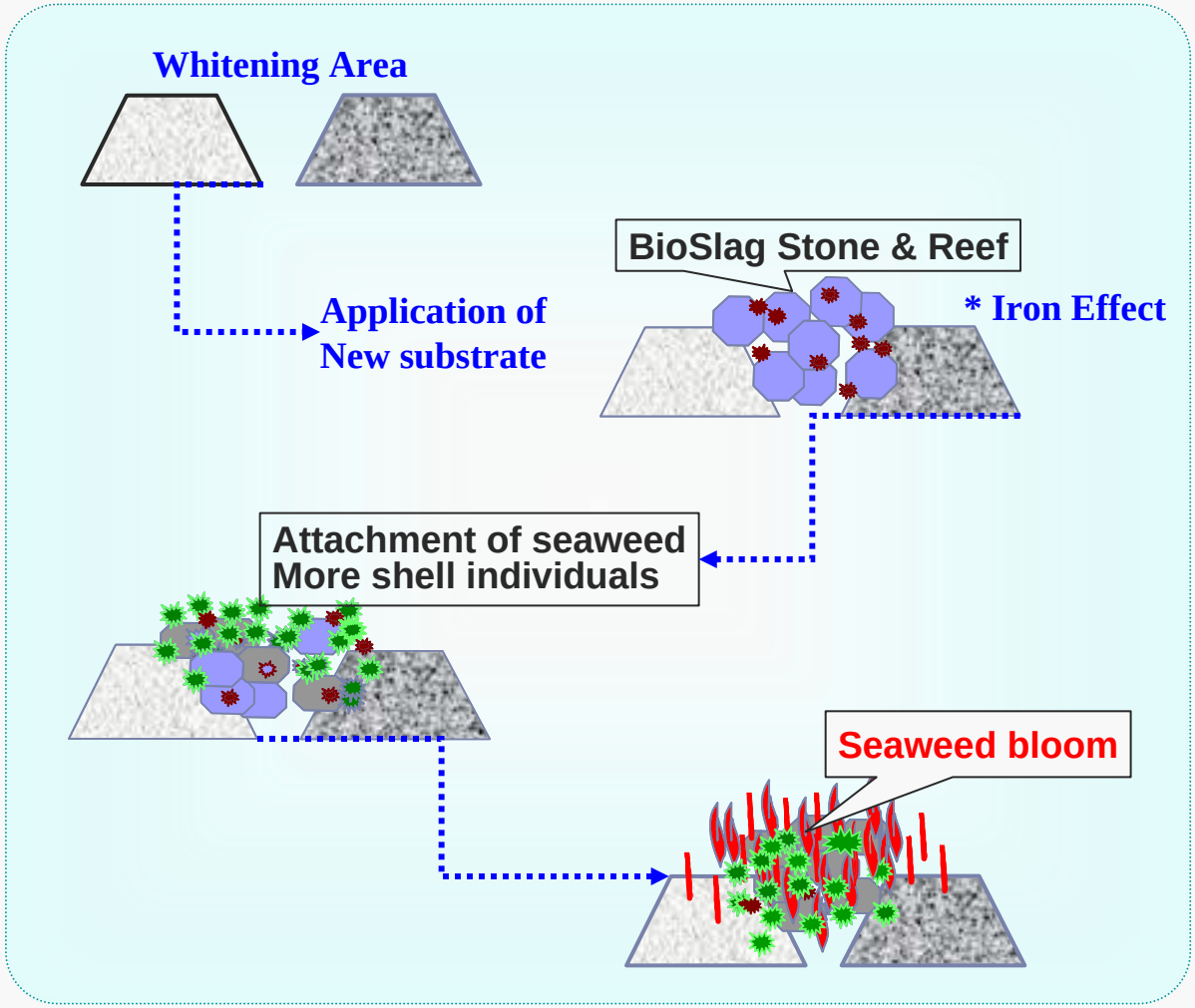
Mechanism for accelerated carbonation

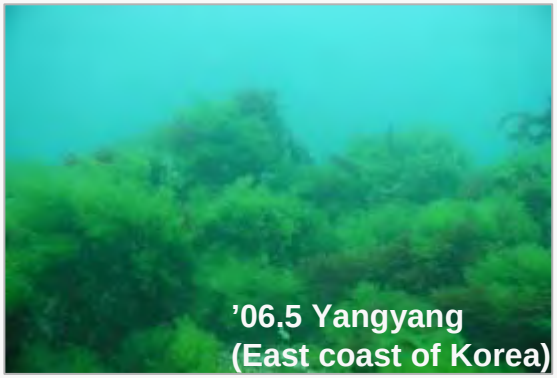


1. Diffusion of CO_2 in air
2. Permeation of CO_2 through the solid
3. Solvation of $CO_{2(g)}$ to $CO_{2(aq)}$
4. Hydration of $CO_{2(aq)}$ to H_2CO_3
5. Ionization of H_2CO_3 to H^+, HCO_3^-, CO_3^{2-} (pH fall from 11 to 8)
6. Dissolution of cementitious phases C_3S and C_2S (cyclic and generating a considerable exotherm)
7. Nucleation of $CaCO_3$, C–S–H
8. Precipitation of solid phases
9. Secondary carbonation

(J. Hazardous Materials, 2004)

Seaweed Beds Restoration Model

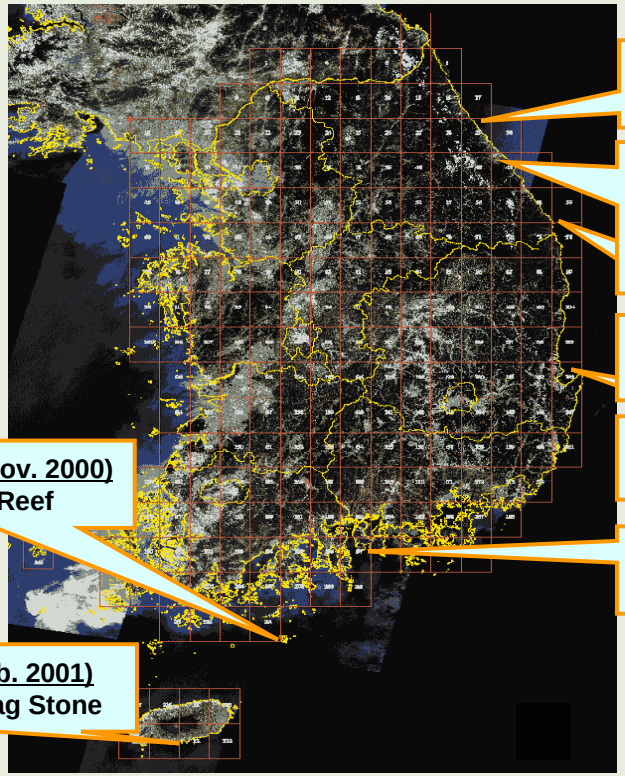




RIST / Gangnung-Wonju Nat'l Univ. (2004)

Results of BioSlag Application Study

Adaptation: Restoration of Seaweed Beds



Namae, Yangyang (Jun. 2005)
3,000 tons, Seaweed Forests

Jeongdongjin, Gangneung (Oct. 2004)
450 tons, BioSlag Stone
(Dec. 2005)
450 EA, Seaweed Reef

Hosan, Samcheok (Dec. 2006)
450 EA, Seaweed Reef

Cheongjin, Pohang (Feb. 2008)
25,000 tons, Seaweed Forests

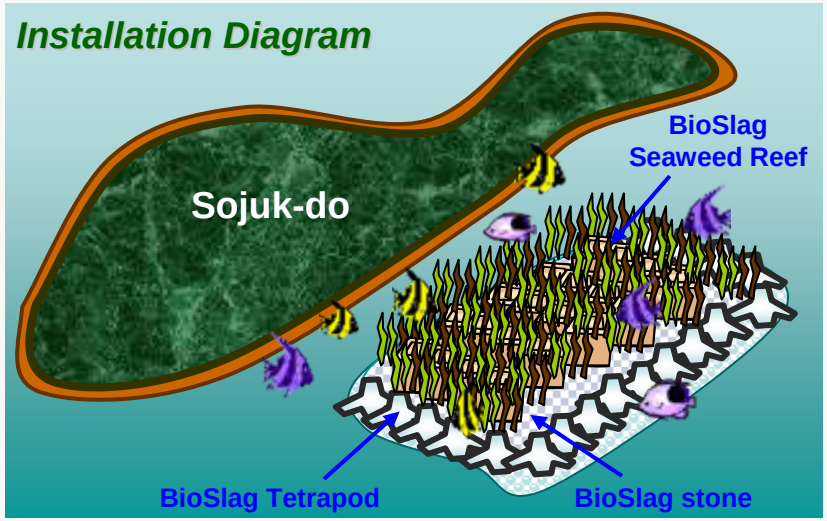
Pyeongsan, Namhae (Nov. 2007)
16,000 tons, Seaweed Forests

Geomundo (Nov. 2000)
179 EA, Fish Reef

Seogwipo (Feb. 2001)
5 tons, BioSlag Stone

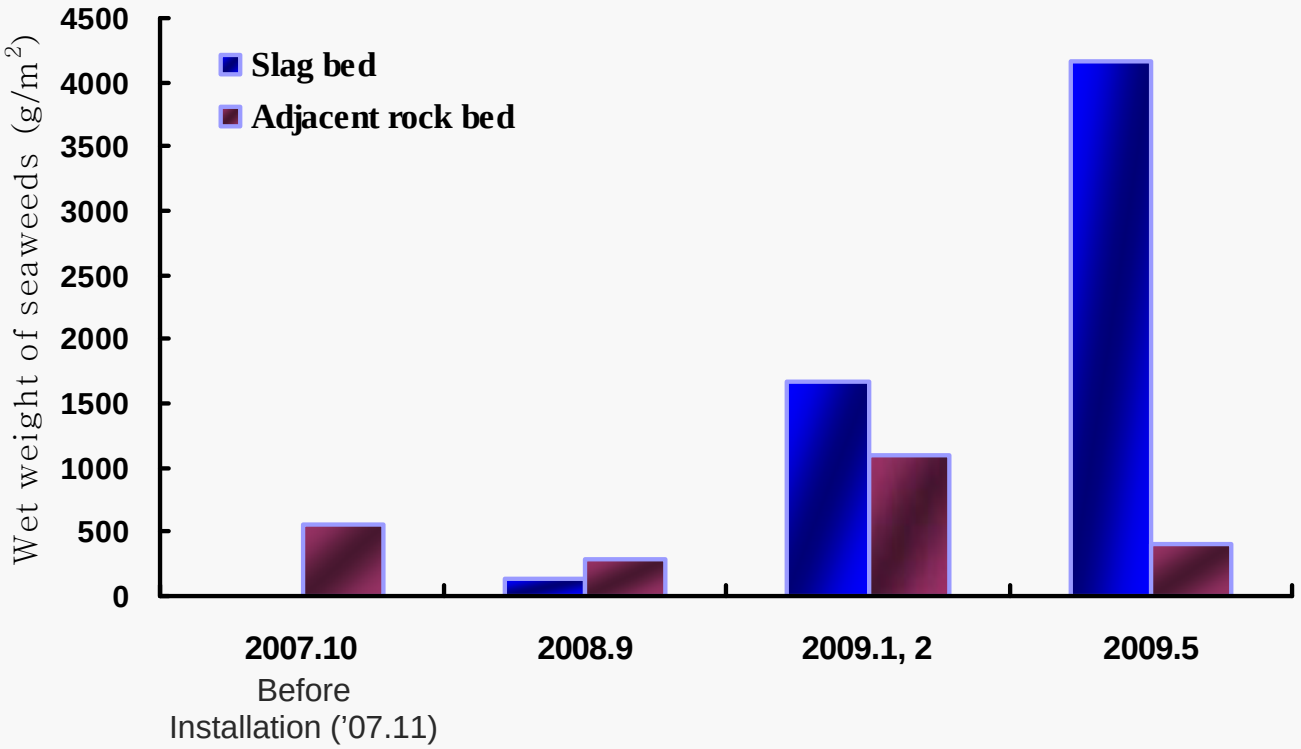
✓ More effective attachment and growth of seaweed on BioSlag product than on other materials

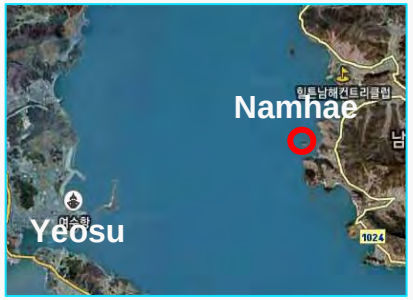
Case study in Namhae Island, South Coast of Korea



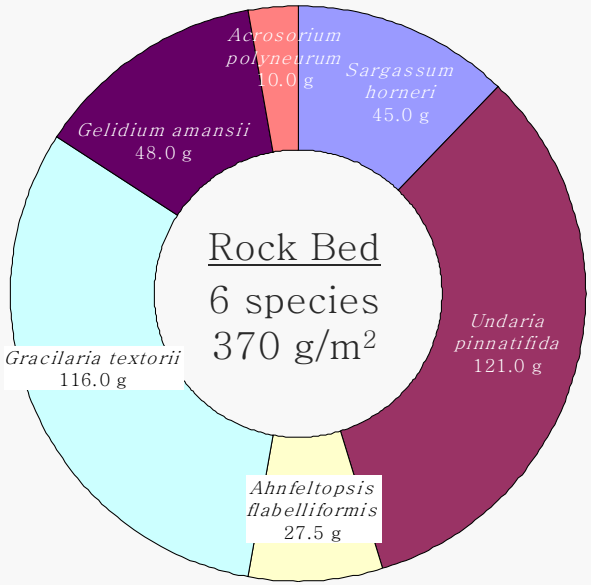
Underwater photo

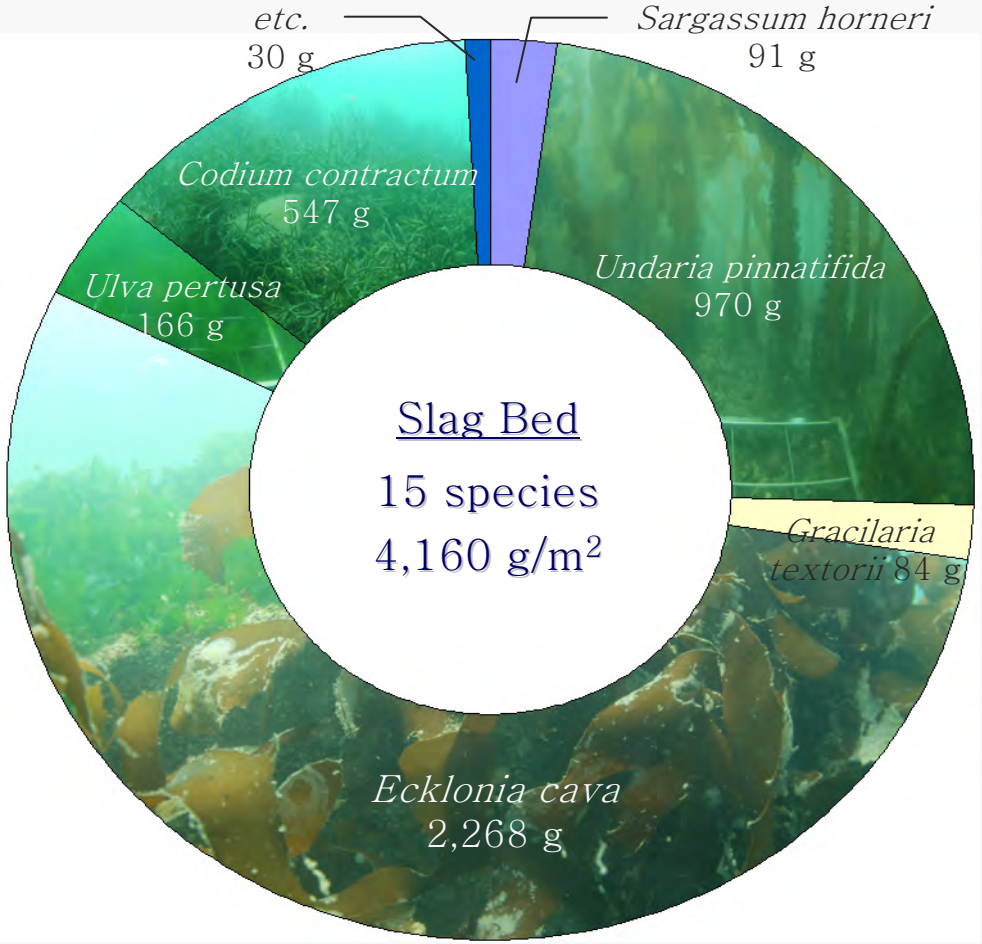
※ Comparison of seaweed weight on each bed





※ Distribution of seaweed species





✓ **Most dominant species on the slag bed is *Ecklonia cava***

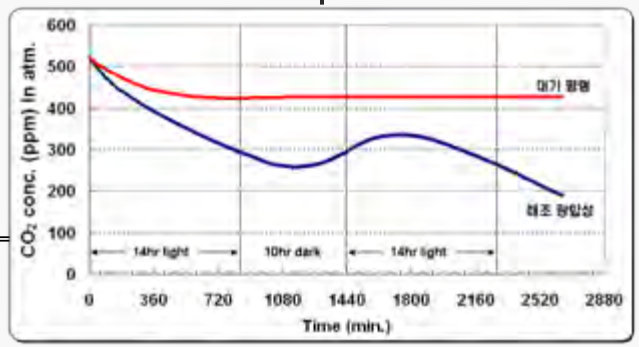
Mitigation: CO_2 Fixation by Seaweeds

Wet weight and CO_2 uptake rate on various seaweed beds in Korea

	Wet weight (g/m^2)	CO_2 uptake ($g/m^2/yr$)
Slag bed (East Coast, 3yrs)	3,720	7,820
Slag bed (Geomun Island, 7yrs)	4,330	11,490
Artificial reef (East Coast)	660	-
Artificial reef (South Coast)	580	-
Artificial reef (Jeju Island)	640	-
Artificial reef (standard)	1,900	-
Ecklonia cava (Jeju Island, A)	2,080	5,520
Ecklonia cava (Jeju Island, B)	1,770	4,700
Ecklonia cava (Jeju Island, C)	1,630	4,320
Ecklonia cava (Jeju Island, D)	1,550	4,120
Ecklonia cava (Jeju Island, E)	1,320	3,500
Ecklonia cava (Jeju Island, F)	1,220	3,220

78 t-CO_2/ha/yr
115 t-CO_2/ha/yr

Calculation from CO_2 reduction rate of each species FW



Chemical analysis of CO_2 uptake amounts by seaweeds on slag bed

Measurement of 2 parameters (TCO_2, TA)

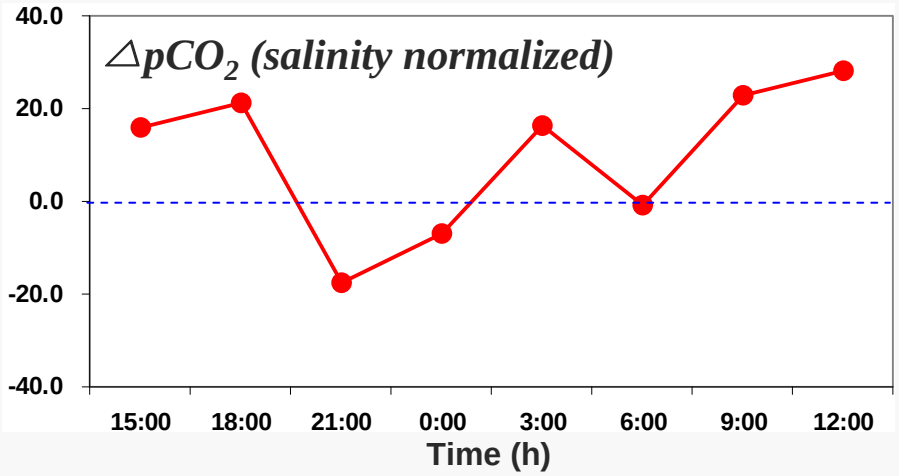
Using Thermodynamic Model

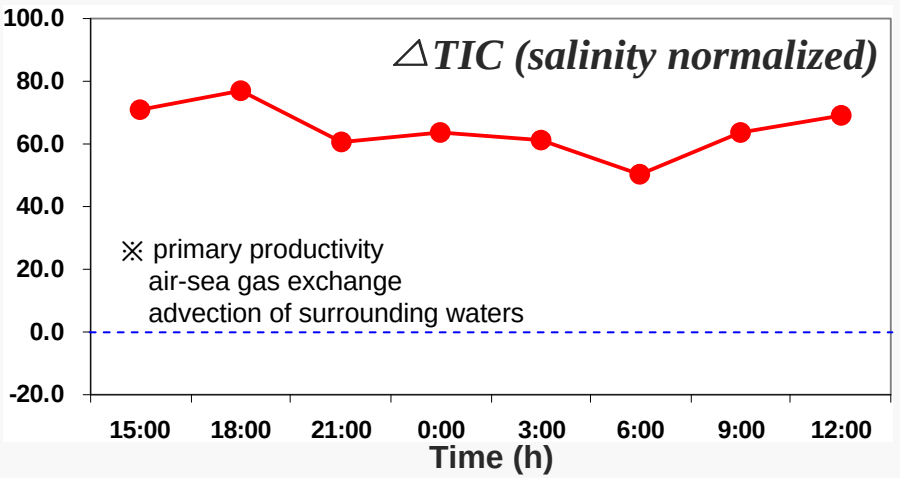
$TA = [HCO_3^-] + 2[CO_3^{2-}] + [H_2BO_3^-] - [H^+]$

$TCO_2 = [HCO_3^-] + [CO_3^{2-}] + [CO_2(g)]$

$pH = -\log[H^+]$

➔ pCO_2 calculation





$\delta\ CO_2 = pCO_{2\ control} - pCO_{2\ in\ bed}$

(+; sink, -; source)

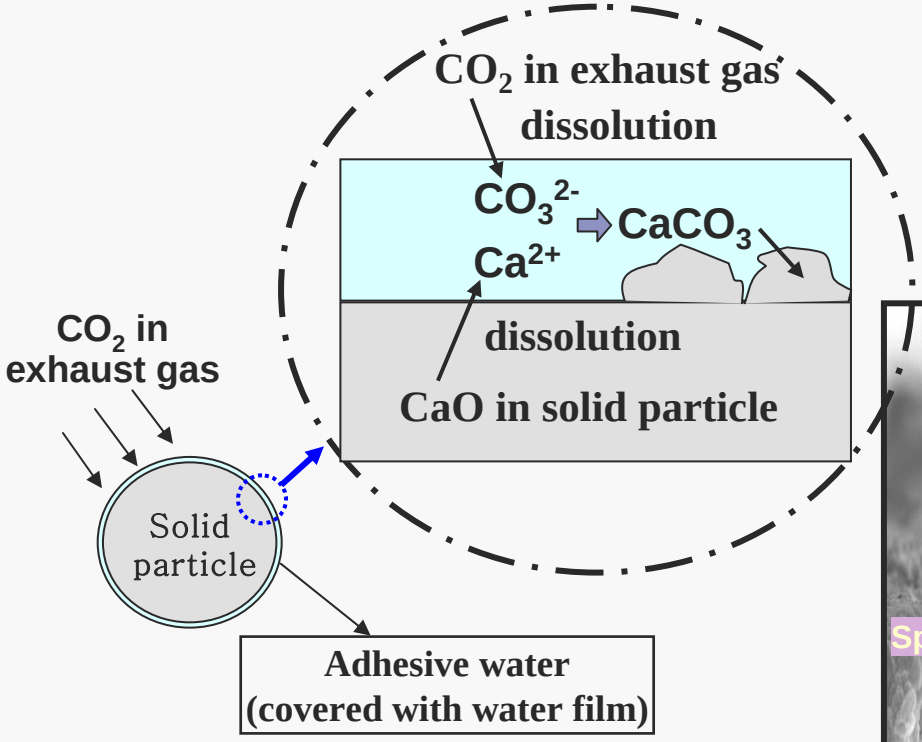
$= +\ 9.8\ \mu atm$

$\delta\ TIC = TIC_{control} - TIC_{in\ bed}$

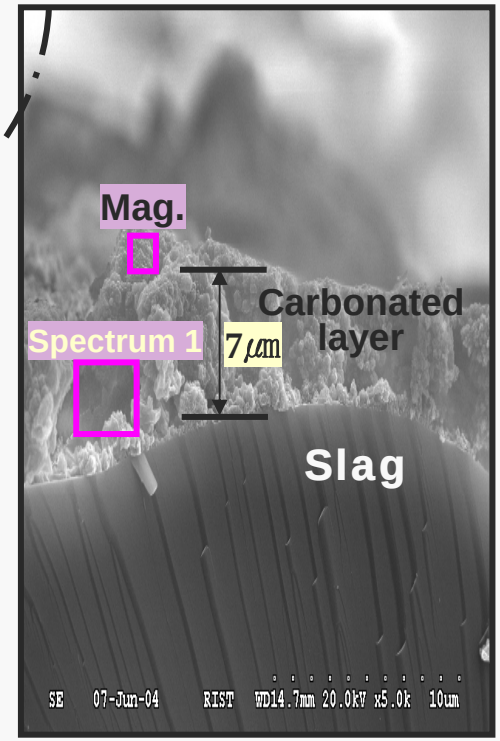
$= 64.7\ \mu mol/kg$

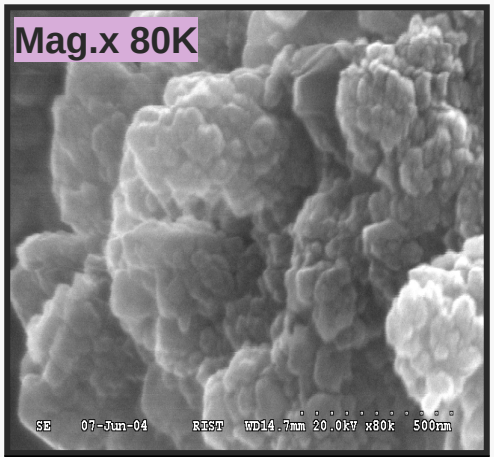
➔ $3.9\ gCm^{-2}d^{-1} \approx 5{,}200\ gCO_2m^{-2}yr^{-1}$

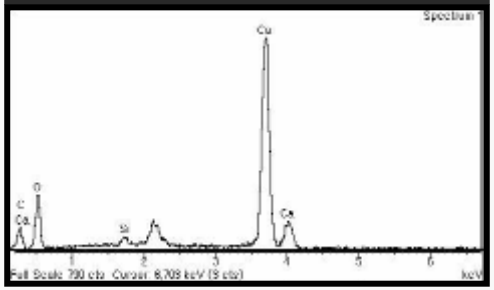
Mitigation: Carbonation of Steelmaking Slag



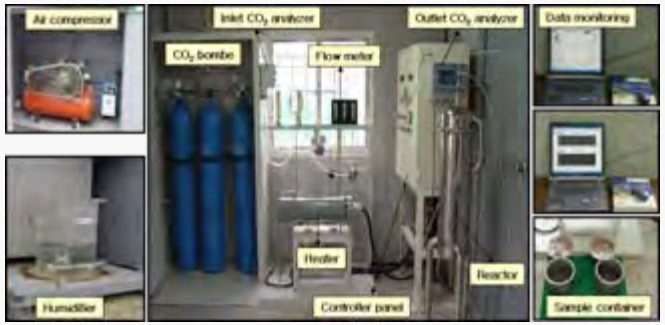
Formation of $CaCO_3$ layer on the surface of slag

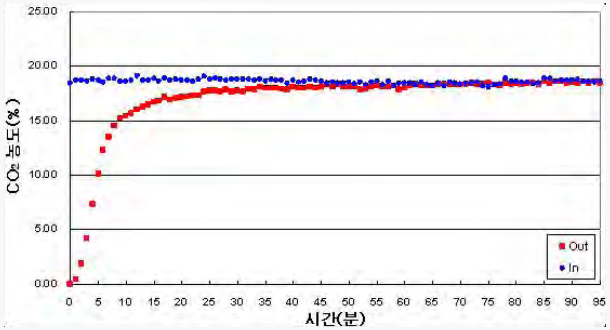


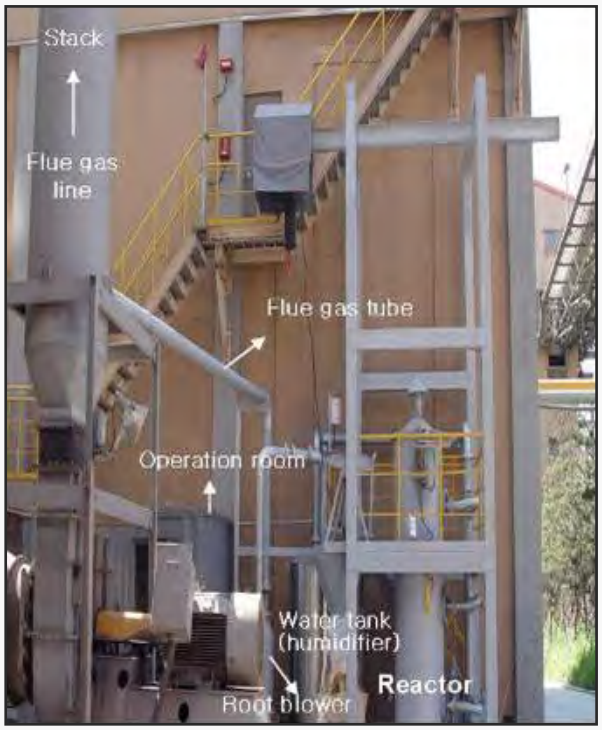


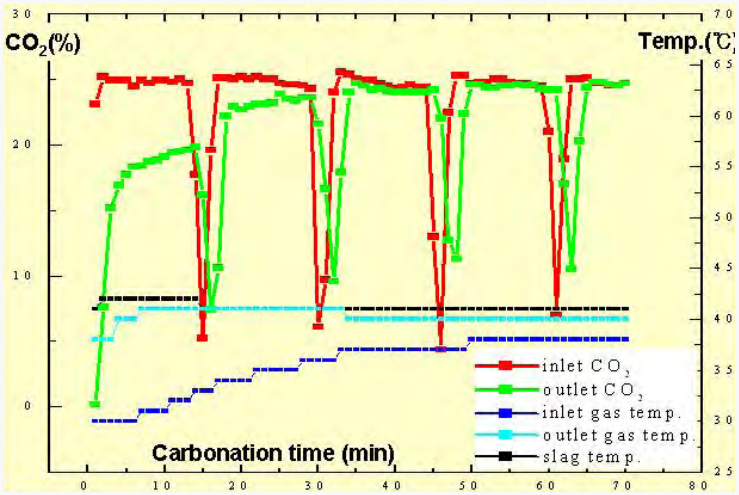


Lab. & Pilot Test *(limestone calcination plant in Pohang Steel Works)*









✓ **Sequestered amount of CO_2 : ~0.3 t-CO_2/ton-slag**

- **Slag size 20~40 mm**
- **Moisture content 4.5%**
- **CO_2 ~25% v/v**

Ongoing Activities with Korean Gov.

- **Subject : Memorandum of Understanding Between the MLTM (former MOMAF) and POSCO for Mutual Cooperation with Marine Climate Change (Nov. 19, 2007)**

- **Major Collaboration Projects**

1) Adaptation to marine climate change

- Biological impact assessment research of slag for marine utilization
- **Restoration of coastal ecosystems using steelmaking slag**
- **CO_2 fixation and bio-energy development using coastal seaweed belt**

2) Preparation of policy & system for marine climate change

3) CO_2 capture and storage (CCS) R&D

4) International cooperation regarding marine climate change

Conclusions

- Marine utilization of BioSlag would be a helpful measure for adaptation to coastal climate change and also for mitigation of CO_2.
- RIST & POSCO will continue collaborative work with Korean Government in response to coastal climate change through promotion of seaweed belt and CO_2 mitigation using BioSlag beds.


THANK YOU
FOR YOUR KIND ATTENTION !